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KNOWLEDGE BASE APPLICATIONS TO ADAPTIVE SPACE-TIME PROCESSING, VOLUME V: KNOWLEDGE-BASED TRACKER RULE BOOK

ITT Systems

Technology Service Corporation

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13. ABSTRACT *(Maximum 200 words)*
The knowledge-based tracker provides the system's knowledge-based controller with: 1) a very accurate prediction of each target's location and kinematics for an ensuing radar dwell, and 2) knowledge of the target's line-of-sight visibility, the competing clutter conditions, and interference at the predicted location so that the optimal radar parameters and space-time adaptive processing algorithm can be applied.

The proactive knowledge-based tracker uses information from other sources such as digital terrain maps, radar clutter and interference maps, and target priority assessments to determine the nature of the threat, evaluate the local environment, anticipate the target's actions, and enhance the prediction of the target's location for the next radar observation.

This report describes twenty-five potential rules for a knowledge-based tracking system.

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1.0 Introduction

The primary objective of the KBT is to provide the system's Knowledge-Based (KB) Controller with: 1) a very accurate prediction of each target's location, kinematics, etc. for an ensuing radar dwell, and 2) knowledge of the target's line-of-sight (LOS) visibility, the competing clutter conditions, interference, etc. at the predicted location so that the optimal radar parameters and Space-Time Adaptive Processing (STAP) algorithm can be applied. The rules that TSC will test using the tracker simulation that is being developed to support the KBSTAP program are contained in this document.

The concept that is presented results in *pro-active* tracking. A conventional tracker *reacts* to target maneuvers, missed detections, etc. As a consequence, there can be significant errors in the predicted target location, especially when maneuvers occur. Additionally, the uncertainty ellipsoid about the predicted target position will become large if data-to-track associations cannot be made. This will result in correspondingly-larger target acquisition windows for subsequent scans, which can cause incorrect data-to-track associations and susceptibility to false alarms, and will require the use of additional radar resources for maintaining target tracks.

The pro-active KBT will use information from other sources such as digital terrain maps, radar clutter and interference maps, and target priority assessments to:

1. Determine the nature of the threat,
2. Evaluate the local environment,
3. Anticipate the target's actions, and
4. Enhance the prediction of the target's location for the next radar observation.

As will be discussed in the following sections, the overall system performance can be significantly enhanced by this improved target location accuracy.

2.0 KBT Design Rationale

A very wide variety of rules and techniques can be postulated to improve the performance of the tracker, especially if computational resources are not a major constraint. To keep the KBT design problem focused and bounded, this effort is concentrating on the development of rules that should directly affect the performance of a STAP-based air surveillance radar system that uses track-while-scan (TWS) processing. The radar system can have either a regular target revisit rate (e.g. the mechanically-scanned E-3A AWACS) or have dynamic control of the target revisit and dwell times (e.g. an electronically-steered array antenna). The KBT concept is readily extended for ground moving target tracking in a Joint STARS type of radar.

The incorporation of a KBT into such a radar system will provide the greatest benefit in the tracking of low-observable (LO), high-priority targets in severe interference environments. If a very accurate prediction of each target's location and kinematics for the next radar observation can be made, then several important advantages can be achieved in the system operation, including:

1. Optimizing the radar waveform parameters (e.g. frequency, PRF), dwell time, coherent processing interval (CPI), number of CPIs per dwell, target revisit time and the STAP algorithm to maximize the signal-to-interference ratios (SIRs) of the high-priority LO targets.

2. Optimizing the positioning and dimensions of the target acquisition window, which in turn will minimize the probability of both false detections and misassociations, and will allow the use of a reduced threshold level to enhance the target detection within a portion of the acquisition window.

3. Optimizing the location and the number of range gates excluded from the secondary data set that is used to form the interference sample covariance matrix, **R.**

4. Optimizing the utilization of the overall system resources, including transmitted signal energy, the system time-lines and the computational devices.

The third item listed above is possibly the most important for an adaptive radar system. If the target return is present in **R**, it can be significantly suppressed by the STAP operation. It is unlikely, however, that there will always be sufficient computational resources to form a unique **R** for each range gate. By providing an accurate indication of each target's range, Doppler frequency and azimuth angle, a minimal number of range-Doppler-angle cells can be omitted from **R**, thereby minimizing the probability of suppressing the target while simultaneously maximizing the number of suitable independent clutter samples available to form **R**.

3.0 KBT Design Assumptions

The following data is assumed to be available to the KBT:

1. Target Range, azimuth angle, altitude, SNR, Doppler frequency/velocity, etc. as available from the radar measurements overlays (surrogate data will be used where necessary to supplement the KBT simulation).

2. Target priority (user input for the KBT simulation).

3. Digital topography and terrain cover maps with road overlays and locations of large stationary *discretes*. Discretes are objects such as large buildings and bridges whose radar cross-section (RCS) are often greater than 50 dBsm, which can result in MTI filter *break-throughs*.

4. Clutter maps, generated by the radar, providing *absolute* clutter-to-noise ratio (CNR) data (including STC and AGC effects of the local environment), and the detection threshold relative to the system noise level overlays.

5. Radar parameter values that will allow measurement accuracies and resolutions, range and velocity blinds, etc. to be determined.

6. Tracking data for other sensors including radars, IFFs, ESMs, INTEL sensors and secure datalink GPS reports from friendly targets. Surrogate data will be used in the KBR simulation, primarily for establishing the target priority (if done dynamically), for track continuation when the target cannot be detected by the radar and to support the track promotion logic.

No additional target discriminants (e.g. RSM lines, HRR profiles, ISAR images) will be provided to the KBT by the radar.

The KBT will be developed in two dimensions, with altitude serving as a target discriminant when available. The KBT will not track in the vertical dimension. The altitudes of the targets will be assumed to be known from devices such as continuous radar observations (elevation scan for an E-3A AWACS), IFF reports and secure, GPS-based position reports. This will allow for conditions such as target obscurations by the terrain and obstacle avoidance flight paths to be evaluated by the KB Controller.

The high-priority, LO target for which the KBT is being structured is assumed to fly at a virtually constant, sub-sonic speed (Mach 0.4 to 0.7) and at a low altitude (e.g. $\leq$ 300 m). The target turns are assumed to be constant-G, i.e. to be arcs of circles, and to be of 2 Gs or less. From the literature, these assumptions appear to be indicative of the performance of the unmanned, low-altitude, LO aircraft that radars using STAP will be designed to detect and track. Probable start and end points (or regions) at which the LO targets would perform such maneuvers will be determined from the digital database by the system's KB Controller. This assumption has been incorporated into the KBT design. It has also been assumed that locations at which obscurations or strong clutter residues will probably occur can be determined from this database.

When a low degree-of-freedom (DOF) STAP architecture is used, the adaptive processing will be principally concerned with the rejection of mainlobe clutter. This is a reasonable assumption for a range-unambiguous waveform, as the two-way antenna pattern sidelobe level should be sufficient to reject all but the strongest sidelobe clutter. (Discretes in the sidelobes will be tracked and censored.) In such a system, if adaptive $\Sigma \pm j\Delta$ DPCA processing is used, however, it may not be possible to perform monopulse processing, as the difference (Δ) pattern channel signal is used in performing the clutter cancellation operation. Thus a beam centroiding (as opposed to a monopulse) angle accuracy estimate will be assumed in the development of the KBT when this STAP technique is utilized. Performing beam centroiding will require the antenna to scan from CPI to CPI.

It is also noted that such a system, major roads that lie along the radar's line-of-sight (LOS) vector can cause a significant amount of the range-Doppler plane to be contaminated with ground traffic returns. High speed, two-way traffic (e.g. $\pm$ 35 m/s) returns are a significant concern for low PRF (e.g. 325 Hz, which is range-ambiguous to nominally 250 nmi) radars. This is because the Doppler bandwidth of the ground traffic ($4v/\lambda$) will overlap a very large

fraction of the PRF. The KBT will monitor locations where roads fall within the mainlobe and censor portions of the data that may be corrupted by ground traffic returns.

4.0 KBT Figure of Merit (FOM)

The FOM for the KBT will be a function of both 1) the difference between the predicted and the actual target positions over an experiment and 2) the volume of the data association window. Item 2 is required because the actual target cell must be excluded from R to ensure that it is not suppressed by the STAP. Hence a target location prediction that has a somewhat larger error, but that includes the target return cell can be of greater benefit than a prediction that has a lower mean error, but whose dimensions are made too small and does not include the actual target cell. In this latter case, the STAP operations could suppress the target by a sufficient amount to prevent its detection.

For the initial KBT assessments, the following FOM will be used. The objective is to minimize the FOM:

$$\text{FOM} = \Sigma\{\text{Distance from Prediction to Truth}^2 + [\sigma_x^2 + \sigma_y^2 + T^2(\sigma_{vx}^2 + \sigma_{vy}^2)] + \text{Penalty}\}$$

where T is the time between radar dwells. The summation will be over all points at which the KBT predicts the target's position and velocity. The penalty for the actual target location falling outside of the association window is TBD, and conceivably could be multiplicative as opposed to additive.

5.0 Surveillance Mission Requirements

There is a caution that has been considered in the KBT design relative to the KB Controller. The KBT rules that are presented in this document are designed to give the best overall tracking performance for targets that have already been detected. However, the radar must also be responsive to the task of detecting targets that have not previously been observed. Thus, it has been assumed in the KBT that the optimal action for tracking may not always be the optimal action for the best overall system performance, and hence that less-than-optimal data may be supplied by the radar on any particular radar dwell.

6.0 Target Priority

It will not be possible in the KBT simulation to dynamically control the target priority based on information about the target that is supplied by external sources. Therefore, the method by which the target priority could be controlled in an actual system will be briefly discussed.

Information about the target can be obtained from a large and diverse number of data sources. Among these are:

1. Orientation of target track / launch location

2. Probable objective (i.e. the end point of the target track)

3. Radar signature of target (e.g. radar cross section, fluctuation statistics, RSM signature, high-range resolution profile, ISAR image,)

4. Intelligence (INTEL) reports

5. ESM analysis of the target's radar, altimeter, IFF and communications signals

6. Flight path characteristics (e.g. heading, speed, altitude, turn rate)

7. Jamming activity

By accumulating such information and correctly associating it with a specified target track, the KB Controller will be able to identify the target, deduce the nature of the threat and dynamically alter its priority. As the priority changes, the KBT would act to apply an appropriate percentage of its available resources to ensure that tracks are maintained on the most critical threats.

The inclusion of all of these information sources is well beyond the resources of this program. However, by using an actual digital terrain map of a challenging scenario and supplying surrogate variations of the target's priority, the KBT will be able to show the dynamic alterations in the tracker architecture that could be achieved by the ultimate system.

7.0 KBT Rule Book Overview

This document contains the rules that will be applied in the KBT. Each rule is presented in boldface type. A discussion of that rule then follows that describes the rationale for the rule and how it will operate in the KBT. The impact of the rule on the overall KB system is also presented. Finally, the interface requirements along the KBT, the KB Controller and the radar is provided.

In several of the rules it was necessary to use qualitative, or *fuzzy*, terms such as *close* to describe a particular condition. The use of such terms is highlighted in italics. As the rules mature, a more quantitative description of these fuzzy terms will be provided. Also, several of the data items that are listed for the interface between the KBT and the KB Controller are listed as being optional. This is because the information provided by these data items could be processed in the KBT or they could be processed in the KB Controller and a simple yes/no flag could be sent to the KBT, or vice versa.

8.0 KBT Description, Operational Concept and Functional Flow

8.1 Introduction

This section of the document will describe the components of the KBT and its operational concept. The functional flow of the data through the KBT will also be described. A key element of the discussion will be the data that is required by the KBT, when and from where it is obtained, and the data that the KBT will provide to the KB Controller and to the radar. A database will be maintained that will serve as the device through which all radar, scenario,

terrain, cultural, and target data (other than target reports that are passed directly from the radar to the KBT after post-detection processing) will be passed.

The priority of the target is the only information that cannot be derived from the radar measurements or the topographic / land cover / road databases. The priority will be assigned by the KB Controller. The most efficient means to change the priority of a target appears to be for the KB Controller to examine the database to determine which target correlates with information that could change its priority, to change the priority as appropriate, and then to change the priority of the target track number in the database and the KBT. The **Target Priority Rule** describes the target priority levels.

8.2 Database

A key element of the KBSTAP system will be a digital database that contains all relevant radar, scenario, target, terrain, and cultural data. The KBT will access this database, which will be used in common by all elements of the KBSTAP system, to obtain information about the operating environment, and will input to the database information about targets, discretes and ground traffic. Among the information contained in the database will be the following:

1. Topographic data in Cartesian coordinates
2. Terrain cover type.
3. Absolute detection threshold (i.e. relative to the system noise level) for the most recent detection process operation for each (x, y) location. This *CFAR map* will also serve as a measure of the residual clutter or jamming power for the test cell.
4. Locations and orientations of roads and railroads.
5. Locations of discretes.
6. Height above terrain of a target to be visible to the radar for each (x, y) location.
7. Locations of blind ranges and velocities.
8. Locations, altitudes, headings and velocities of all targets under track.
9. Dimensions of the uncertainty ellipsoids for targets under track.
10. Priority and estimated vehicle type for targets under track.
11. Time tag for all information entered into the database, including times for which it should be deleted.

The database will be dynamic. For example, the radar location, the target locations, the LOS visibility to the radar, etc. will constantly be changing. This data will be entered to the database as it becomes available or when it is updated. Also, as features such as discretes and roads that may not be in the database are identified, their locations can be entered.

8.3 Post-Detection Processor

The Post-Detection Processor is the interface between the CFAR detection logic and the KBT. The purpose of this device is to convert the radar data into a form that is usable by the tracker. The operations that are assumed to be performed by the Post-Detection Processor are:

1. Resolving of range and/or velocity ambiguities of the radar waveform.
2. Estimation of the SNR for the detection.
3. Centroiding of multiple CPI data.
4. Conversion of the detection location into Cartesian coordinates referenced to the database.
5. Conversion from Doppler frequency / radial velocity to dx/dt and dy/dt.
6. Conversion from elevation angle to target altitude.
7. Calculation of the measurement uncertainties (i.e. the standard deviations of the measurement errors).

There are a number of radar parameters that must be known in order to determine the measurement uncertainties. These include the following:

1. Range resolution / range gate splitting constant / range bias error
2. Azimuth resolution / azimuth beam splitting constant / azimuth bias error
3. Velocity resolution / velocity filter splitting constant / velocity bias error
4. Number of CPIs on which detections were made
5. SNR of detection report

Using this data, the Post-Detection Processor will determine the standard deviations of the measurement errors using the equations provided below. The splitting constants, K are the factors that relate the resolutions to the accuracies when determining the standard deviations of the measurement errors. These constants and the bias errors will reflect the type of processing that is currently being performed (e.g. monopulse or centroiding), the time since the last system calibration, etc. This information need not be passed for each target detection if the radar parameters are fixed; however if, for example, monopulse processing is used and the azimuth beamwidth changes with the scan angle, then this information must be transmitted to the Post-Detection Processor.

The general form of the measurement uncertainty parameters and equations are as follows:

R	=	Range from radar to target
θ	=	Azimuth angle from radar to target ($\theta = 0$ is x-axis)
n	=	Number of CPIs on which a threshold crossing occurred during the target dwell
SNR	=	Average signal-to-noise ratio of the threshold crossings
ΔR	=	Range resolution = c/2B
$\Delta\theta$	=	Azimuth resolution (i.e. the azimuth beamwidth, including scanning and STAP effects)
	=	Radial velocity of target (i.e. velocity along radar LOS vector). (This quantity may be ambiguous)
fd	=	Target Doppler frequency = $2Vr/\lambda$
Δfd	=	Doppler frequency resolution = k / Coherent dwell time
ΔV_r	=	$\lambda \Delta fd/2$
x_{target}	=	$R\cos(\theta) + x_{radar}$
y_{target}	=	$R\sin(\theta) + y_{radar}$
σR	=	$K_R \Delta R/(nSNR)^{1/2}$ + Bias error
$\sigma\theta$	=	$K_\theta \Delta\theta/(nSNR)^{1/2}$ + Bias error
σV_r	=	$K_{Vr} \Delta Vr/(nSNR)^{1/2}$ + Bias error
σx	=	$[(\sigma R\cos(\theta))^2 + (R\sigma\theta\sin))^2]^{1/2}$
σy	=	$[(\sigma R\sin(\theta))^2 + (R\sigma\theta\cos))^2]^{1/2}$

The detection report sent to the KBT will include x_{target}, y_{target}, Vr, σx, σy, σV_r, and SNR, assuming that Vr is available. In addition, the KBT will require the following data from the radar for each detection report:

1. Time of detection
2. Estimated height of target (if available from radar processing)

3. Maximum unambiguous velocity of radar waveform

4. Detection threshold crossed (i.e. NORMAL, LOW or VERY-LOW)

These quantities are necessary to refine the position estimate if the time between target measurements is different than used for the initial prediction, to determine if the LOS vector to a target could be obscured, to know which Track State Promotion Logic is effected, etc. The SNR and the ambiguous radial velocity can also serve as a discriminant when performing data-to-track association. The SNR can be useful when a large and a small target cross paths. Knowledge of the ambiguous velocity of the detection report and the maximum unambiguous velocity of the radar can limit the number of possible velocities to be considered in the data-to-track association processing.

The KBT will send the following data to the database:

1. Track number

2. Smoothed x, y , dx/dt and dy/dt values for the most recent observation (if requested)

3. Time-tag for the smoothed observation

4. Predicted x, y, dx/dt and dy/dt values for the next observation

5. Time-tag for the next observation

6. Track state

7. SNR

8. Target height

9. Target priority

8.4 KBT Components

The KBT, which consists of three principal components, is illustrated in Figure X-1. These functions are discussed in several texts of multiple target tracking, and hence will only be briefly described in this section.

8.4.1 Data-to-Track Association Logic:

This device is used to either assign a detection report to an existing track or to spawn a new track. The assignment can either be immediate, assigning the data that minimizes the RMS error if multiple detections and/or multiple tracks exist within the association window, or can be delayed for high-priority targets. When the decision is delayed, multiple hypothesis testing (MHT) will be performed. Under MHT, several possible tracks may have

to be evaluated for several radar scans to ensure that the correct association of the detection reports and the tracks have been made.

8.4.2 Tracking Filter:

This devise is used to predict where the target will be on the next radar scan. It will combine this prediction with the radar measurement to provide a smoothed estimate. Either a fixed coefficient, $\alpha\beta$ or $\alpha\beta\gamma$ filter or a Kalman filter can be used. The Kalman tracking filter will also provide uncertainty ellipsoids that identify the 3σ region of target uncertainty about the predicted location.

8.4.3 Track State Promotion Logic (TSPL):

This device provides a measure of confidence in the target track, based on the number of detections / no-detections that have occurred on the most recent radar scans. In the design that will be discussed in this write-up, track state S3 will denote a confirmed track. For the KBT, a target will have to be in track state S3 before it is entered into the database.

8.5 Operational Concept / Functional Flow

The operation of the KBT and the data transfer requirements among the KBT, the database, the KB Controller and the radar will be discussed in the following text. The operation will be described in relation to the various functions that the KBT must perform, e.g., track initiation, maneuver detection, stationary target (i.e. discrete) identification, etc.

8.5.1 Track Initiation:

The first step in the KBT process is to initiate the track. Unless 1) the KB Controller sends a message to the KBT that a high-priority track is to be initiated, or 2) the KBT is attempting to re-initiate a track on a high-priority track that has been lost, the KBT will operate in much the same manner as a conventional tracker. The number of detections that are required are shown under the **Track State Promotion Logic (TSPL) Assignment Rule**. A target track will not be entered into the database until it has reached the S3 (CONFIRMED) track state. Therefore, there will be no interface with the radar or the KB Controller at this time. When performing track association, an $\alpha\beta(\gamma)$ filter will be used.

The functional flow for track initiation is that the KBT will receive the target data (location, velocity, SNR) from the radar and process these detection reports until either the track is dropped or a confirmed track state is reached. Upon reaching a confirmed track state, the estimated target position and velocity for the next radar scan will be entered into the database. If a Kalman filter is assigned to the track, the uncertainty ellipsoids for the predicted position and velocity will also be entered.

8.5.2 Position Velocity Prediction:

Once a track has been established, the tracker will provide predictions of the location and velocity of the target on the subsequent scan. The purpose of the KBT is to predict these quantities in an *optimal* manner. The KBT must also provide information as to the volume of

uncertainty (i.e. uncertainty ellipsoids) for its predictions, and the increase in this volume if the target were to maneuver during the time between radar scans. This function is similar in the KBT to a conventional tracker, except that the database will be interrogated to determine the nature of the environment at this predicted location.

If it is determined that the target probably cannot be observed at the predicted location due to obscuration, a high detection threshold, ground traffic or a discrete, etc., a flag will be set. The KB Controller, observing this flag, can decide whether or not to exclude cells from the STAP processing for excluding this target.

8.5.3 Non-Maneuver / Maneuver Data-to-Track Association Window:

For each detection report, the KBT must determine which threshold crossing to associate with which track. Thus the next step in the KBT operation is to establish a window of possible locations and velocities into which the target return can occur, given its assumed kinematic capabilities. There will be two data-to-track association windows in the KBT: the non-maneuver window and the maneuver window. The dimensions of the non-maneuver window will be established from the Kalman filter covariance matrix and the measurement uncertainty values contained in the detection report, as explained in the **Data-to-Track Association Window Dimension Rule.** All information for establishing the size of this window is contained in the detection report: no data is required from the database or the KB Controller to establish the non-maneuver window dimensions.

The maneuver window is used to quickly increase the Kalman filter gains if the target track diverges from the assumed model. If a detection occurs in the maneuver window, and a detection does not occur in the non-maneuver window, the maneuver noise in the Kalman filter is immediately increased. An objective of the KBT is to keep the volume of the maneuver window as small as possible to enhance the STAP operation and to minimize the probability of a target / track misassociation.

The information required to optimize the maneuver window location and dimensions is as follows:

1. Maximum-G turn capability of target

2. Locations of obstacles (e.g. would a maneuver in a particular direction be very improbable due to the terrain?)

3. Locations of probable target objectives (e.g. which way would we expect the target to turn?)

Item 2 above can be determined by the KBT from the information in the database. Items 1 and 3 would probably have to be supplied to the KBT by the KB Controller.

8.6 Potential Maneuver Contour Definition/Anticipated Maneuver Conditions/Deterministic Maneuver Conditions:

8.6.1 LOW / VERY LOW Thresholds:

It is highly desirable to maintain tracks on high-priority targets, as the difficulty in re-establishing the correlation between the hostile target and a new track can be extreme. Because of this, the KBT will use a reduced threshold over a limited data-to-track association window volume in an attempt to maintain track on the high-priority targets. The **Detection Threshold Rule** explains how the threshold will be reduced to achieve this.

The LOW and VERY-LOW thresholds will be continuously tested in the radar. This is necessary, as there would be too much of a time delay to re-process the data and test against a reduced threshold.

8.6.2 Coast / Demote Track State Decision:

It is also possible that a detection threshold crossing will not occur in the data-to-track association window. The KBT must also handle this condition in an intelligent manner. Thus, this step in the KBT processing determines whether the track state should be demoted or coasted if a detection does not occur at a predicted location and velocity. This is done in accordance with the **Threshold Bias Consideration Rule,** the **Threshold Bias Consideration Rule,** and the **Track State Coasting Rule.**

In a conventional tracker, the decision to demote is automatic, in the KBT, possible causes for missed detection can be evaluated. Possible causes include zero radial velocity, terrain obscuration, increased detection threshold due to strong clutter or jamming, ground traffic, discretes, etc. In event that any of these conditions are observed, the KBT may not demote the track state.

All of the information necessary to implement this function is available in the database. No additional information is provided to the database by the function, although the dimensions of the uncertainty ellipsoids will be increased due to the extended time between detections.

8.6.3 Track-Before_Detect (T-B-D) Processing:

T-B-D processing is a means of maintaining track of LO targets that have low probability of detections, but will fly non-maneuvering trajectories for extended periods of time. T-B-D will only be applied to CONFIRMED hostile targets that meet these criteria. The Initial algorithm that will be incorporated into the KBT will require the target to meet a 3-of-10 detection criteria to remain under track. Only a non-maneuver window with limited growth will be used. A detailed description of T-B-D processing can be found in RADC-TR-86-68.

The only data necessary to initiate T-B-D processing is the target priority from the KB Controller. The KBT will enter into the database that T-B-D processing is being used on the track and the number of consecutive missed detections if this information can be used to aid in STAP algorithm decisions. A unique T-B-D detection threshold may also be requested.

9.0 KBT Rules

(NOTE: In this section (U) denotes knowledge that would be supplied by the KB Controller in an actual system, but that will be supplied by the user in the simulation.)

9.1 Target Priority Rule:

The target will be assigned a priority based on the present assessment of its threat level. The priority will range from –3 to +3, with +3 being CONFIRMED HOSTILE, 0 being UNKNOWN and –3 being CONFIRMED FRIENDLY or CONFIRMED NEUTRAL. The priority will be dynamically altered as information about the target is obtained.

A target priority is required by the KBT in order to determine what type of detection threshold, data association algorithm (e.g. PDA or MHT) and track state promotion logic should be used. The priority would be established by the KB Controller in an actual system. As the simulation will provide no data such as INTEL, ESM, IFF, radar NCTI reports, the priority for each target will be assigned by the user.

The impact of this rule on the radar is in the allocation of system resources to detection of high-priority targets. The impact of the presence of high-priority targets on the KBT is readily apparent in other KBT rules.

Table TP-1: Definition of Target Priorities

Target Priority	Definition
-3	Confirmed Friendly or Neutral
-2	Probable Friendly or Neutral
-1	Possible Friendly or Neutral
0	Unknown
+1	Possible Hostile
+2	Probable Hostile
+3	Confirmed Hostile

KB / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)

Data required from radar to implement rule: **None**

Data supplied to KB Controller as result of rule: **None**

Data supplied to radar as result of rule: **None**

9.2 Crossing Targets Rule:

If targets cross paths in a manner that creates an uncertainty as to which new target report should be assigned to an existing track, the priority of all of the resulting ambiguous tracking tracks will be assigned the most-hostile priority level that existed prior to the paths crossing. These priorities will be maintained until the ambiguity can be resolved. At that time, the priority of the less-critical target will be appropriately reduced to that which existed before the tracks crossed.

If during the exercising of the KBT simulation, two targets should pass at a distance that could cause their returns to be confused (e.g. both target returns were simultaneously present in the same target acquisition window, then both targets will be assigned the priority of the most critical target until the conflict can be resolved. A record will be maintained for the tracks as to the level of the lower priority, so that priority level can be re-assigned when the target ambiguity has been resolved.

The impact of this rule on the system is that resources must now be devoted to two or more tracks until the priority of the targets can be resolved. This can be significant if the target density becomes high and/or as the situation being monitored becomes critical.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

1. Reassigned target priorities

Data supplied to radar as result of rule:

None

9.3 Conflicting Priorities Rule:

If it is determined that two or more targets will be simultaneously observed on a subsequent radar swell, the KBT will request the KB Controller to select radar parameters that favor the highest priority, lowest Signal-to-Interference Ratio (SIR) target when all other factors are equal. Exceptions to this rule are as follows:

9.3.1 Maneuvering targets:

If a target having the highest priority on the next radar observation is anticipated to be maneuvering, and if no other target tracks for that same observation having the same priority are closer to termination, the maneuvering target will be given preference over the other targets. If all targets having the highest priority for the observation have CONFIRMED (i.e. S3) track states, then this rule will be applied to targets having the next highest priority, etc.

9.3.2 Missed detection state:

If multiple targets having the same priority will be simultaneously observed on the next radar dwell and none are maneuvering, the system will operate to favor the target whose track state is closest to termination. If all of the highest-priority track states are CONFIRMED, preference will be given to a target having the next highest priority that is not in the S3 state. If two or more such targets exist, preference will be given first to the target whose track state is closest to termination, and next to the target with the lowest SIR.

Targets having Priority ≤ 0 are not to be considered under this rule.

This rule is intended to resolve conflicts when multiple targets are present for a radar dwell. In general, the radar parameters that are best for one target are not the best for another. The idea of this rule is to favor the highest priority targets, especially if they are maneuvering and/or have not been reliably detected on recent radar scans. Preference is always given to the most critical targets; however if their tracks are well established and stable, the system may devote some of its resources to the next priority target. **In no case should the tracking of a Priority 2 or 3 target be compromised by devoting radar resources to a target whose priority is ≤ 1.**

The impact of this rule on the KB Controller will be to require it to determine the radar waveform that is best suited for all of the targets that are under track. The impact of this rule on the STAP performance will be that to avoid losing track on the highest priority targets, some sacrifice may be made in the overall surveillance performance of the radar. This may be in conflict with other system requirements. Thus a trade-off may have to be made that considers the priorities of the entire system.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)

2. Target visibility (U?)

3. Possible objective locations in vicinity of high-priority targets (U)

4. Obstacle locations and dimensions in vicinity of high-priority targets (U?)

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

1. Predicted locations and velocities of high-priority targets

2. Regions of uncertainty for high-priority targets

3. Track States

Data supplied to radar as result of rule:

1. Need for additional target updates

9.4 Detection Threshold Rule:

If the Target Priority ≥ 2 and if the Track State = CONFIRMED (i.e. either Track State S3 or M1), and if a detection does not occur at the NORMAL threshold level in either the non-maneuver or the maneuver window, then the data in the non-maneuver acquisition window will be tested at the LOW threshold level.

If the Target Priority = 3 and if the Track State = CONFIRMED, and if a detection does not occur at the LOW threshold level, then: 1) the data in the maneuver acquisition window will be tested at the LOW threshold level, and 2) the data in the non-maneuver acquisition window will be tested at the VERY-LOW threshold level. The track will be bifurcated if a detection is made in the maneuver window, independent of whether a detection is made in the non-maneuver window.

This rule may be terminated if it can be determined that the target is obscured to the radar/s LOS, if a deep multipath fade condition is known to be present, or if severe jamming or clutter conditions exist.

The purpose of this rule is to reduce the probability of a missed detection for the LO target. A missed detection will require that the tracker coast for a radar scan time, which can significantly increase the acquisition window size, or can extend the life time of bifurcated radar tracks. Also, of possibly much greater importance, the priority of the target will have to be re-established if the track is lost.

The assumptions for developing this rule are that: 1) the SNR of the LO target will typically be small, and hence there will be a significant number of missed detections, and 2) the LO target will make relatively few maneuvers due to fuel and control surface limitations. The LOW threshold will be set to a level at which the probability of false alarm will increase by nominally two orders of magnitude (typically about a 2dB threshold reduction) to a value on the order of 10^{-4}. So long as the total number of range-Doppler-angle cells in the acquisition window does not exceed nominally 10^{3}, the probability of a false alarm in the window will be sufficiently small so that few false detections will occur.

For the highest priority targets, the LOW threshold will be applied to the larger maneuver window, and a VERY-LOW threshold, for which the threshold is reduced by nominally another dB and the probability of false alarm is about 10-^{3}, will be applied to the non-maneuver window. (A threshold value that provides a probability of false alarm on the order of 10^{-5} may be required for the maneuver window if it is very large.) As the probability of a false detection in the maneuver window will now be relatively high, the KBT will automatically bifurcate the track, independent of whether a threshold crossing occurred at the VERY-LOW threshold in the non-maneuver window. This will result in two tracks, one assuming a maneuver and the other assuming that the target continued along a straight-line flight path.

For the KBT analysis, the average SNR of the target will typically be ≥15dB; else a sufficient number of threshold crossings would not occur to establish a reliable track. Based on a Swerling Case 1 target, the initial KBT testing will be performed using a detection improvement factor of 4%/dB. Thus, if the detection threshold was reduced by 2 dB and the probability of

detection was 0.5, the KBT simulation would assume that the probability of detection would now be 0.58. The increase in the probability of detection will be much more dramatic if a Swerling Case 0 or Case 3 target model is assumed.

This rule will impact the KB Controller in that there will now be two locations for which the KBT will request a high-priority target dwell be conducted. Radar resources must then be allocated for each possible target position. It is obviously desired to terminate the track for the incorrect hypothesis as rapidly as possible.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)
2. Target visibility (U?)
3. Range or Doppler blind condition exists
4. Severe clutter conditions exist
5. Jamming exists
6. Multipath fade zone exists

Data required from radar to implement rule:

1. SNR of detection (needed to establish measurement uncertainties)
2. Detection threshold (needed in simulation, but not in actual radar)
3. Measurement accuracies ΔR, $\Delta\theta$, Δf_d (needed to establish measurement uncertainties)

Data supplied to KB Controller as result of rule:

1. Number of bifurcated target tracks for high-priority targets
2. Predicted locations and velocities of high-priority targets
3. Regions of uncertainty for high-priority targets
4. Track State

Data supplied to radar as result of rule:

1. Acceptable probability of false alarm (KB Controller must determine threshold)

9.5 Maneuver Anticipation Rule:

If an obstacle is in the path of the target that would require a maneuver in excess of 0.5 G to avoid, or if an estimated primary objective is at a location that would require a maneuver in excess of 0.5 G to be approached, the KBT will increase the maneuver gate noise in proportion to the minimum-G turn necessary to avoid the obstacle or to reach the target. Also, the KBT will limit the maneuver gate noise to the maximum (estimated) maneuver capability of the target. The KBT will apply the maneuver noise in accordance with the Maneuver Detection Window Positioning Rule. The KBT will terminate the Maneuver Anticipation Rule if the obstacle or the target is passed.

If the anticipated maneuver is constrained so that the maneuver *must* be in a particular direction (e.g. the target can or must turn to the right, but not to the left), then the expanded data-to-track association window will be shifted so that it does not overlap the region into which the target cannot travel.

The objectives of this rule are to: 1) minimize that latency of the tracker when a maneuver occurs, 2) to apply only enough maneuver noise to match the most probably target trajectory, and 3) optimally position the data-to-track association window. The concept is to increase the tracking filter gain (i.e. the bias toward favoring the measured over the smoothed data) before the target begins a maneuver by the amount that is calculated by the KB Controller.

A maneuver would be anticipated when:

1. An obstacle is in the target's path (e.g. a hill or a mountain) and it is improbably that the target will climb to cross it, but there are several possible courses of action that the target can take, or

2. A possible objective is in proximity to the target's path, but is not on the present heading.

The actions of the KBT would be to increase the maneuver noise (i.e. to increase the gain) in the filter to be more responsive to target maneuvers, and (if possible) to bias the acquisition window in the direction of the anticipated maneuver for the next target update if all paths for the target are influenced the same constraint (e.g. the target can turn right to avoid an obstacle, but the path to its left is blocked). The Maneuver Anticipation Rule will apply the acceleration noise along a perpendicular to the velocity vector, which is consistent with a constant-G turn.

The payoff for this rule is in the enhanced data-to-track associations, particularly for LO targets that could easily be lost if they fall outside of the predicted maneuver gate. This is especially a problem if a LO target has not been detected during one or more consecutive radar dwells. The KB Controller will have the ability to better select the radar mode and STAP algorithm, given a better prediction of the target's location and velocity, the clutter conditions, etc.

It is noted that a reactive tracker can be made to respond quickly when a detection falls inside of the maneuver gate. Thus the pro-active KBT is only gaining a slight (possibly only one radar dwell) advantage. However, as most maneuvers will be completed with two to four radar dwells, this advantage can be significant. Also, as the KBT will have a reasonable idea of the type of maneuver, the filter should not *over-react* to the situation.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)

2. Possible objective locations in vicinity of high-priority targets (U)

3. Obstacle locations and dimensions in vicinity of high-priority targets (U?)

4. Maximum-G turn capability of high-priority targets

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

1. Region of uncertainty for high-priority targets

Data supplied to radar as result of rule:

1. Need for additional target updates

9.6 Maneuver Detection Window Positioning Rule:

If a detection occurs in the maneuver gate and a detection does not occur in the non-maneuver gate and the overlay of the target's track on the digital terrain database shows 1) an obstacle blocking the original, straight-line flight path, or 2) a probably objective exists along the new target trajectory, then:

1. **The original straight-line flight path will be terminated (i.e. there will be no track bifurcation).**

2. **The subsequent target acquisition window will be placed along the maximum radius constant-G turn (i.e. the minimum acceleration turn) required to avoid the obstacle UNLESS the KBT determines that the target is performing a higher-G maneuver (i.e. the radius of the turn is less than that for the minimum constant-G turn necessary to avoid the obstacle.)**

A Position Locus Curve will be applied to determine the centripetal acceleration.

The purposes of this rule are to enhance the track accuracy and optimize the utilization of the system resources. If the obstacle is NOT a potential objective of the target or if there is no probably target objective immediately behind the obstacle, and if the obstacle cannot be easily traversed without the target expending an inordinate amount of fuel to climb over it, then the target will almost certainly turn to avoid the obstacle. Given this, the LO target will almost certainly continue along a constant-G turn after such a turn has been initiated. Under such circumstances, the continuation of the straight-line flight path or of a lower-G turn can be quickly terminated, which will conserve KBT resources.

The constant-G turn hypothesis will be validated by testing the target measurements against the Position Locus Curve shown in Figure MDWP-1. This curve represents the locus of points of the possible locations of a target for conditions ranging from a constant velocity flight path to a constant, maximum-G turn (in this case 2 Gs). Thus, this curve represents the set of all possible target locations if no linear accelerations occurred during the time between observations. The curve accounts for the possibility that the turn was not continuous during the time between target observations. By observing if and where the target measurement falls on this curve, the nature of the maneuver can rapidly be determined. The next predicted target position can then be biased to favor the continuation of this maneuver.

This rule attempts to avoid the difficulty that a tracker using a linear predictor will have when the target flies along an arc of a circle or other curve that is not well represented by a parabola (i.e. $vT + 0.5aT^2$). By biasing the smoothed position estimate towards the constant radius turn contour, the tracking error should be reduced. This biasing must be terminated immediately after a point is reached for which the maneuver has probably ended.

This rule will benefit the STAP by providing higher-accuracy target data and conserving system resources by not pursuing the straight-line flight path when it is a low probability hypothesis.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)
2. Possible objective locations in vicinity of high-priority targets (U)
3. Obstacle locations and dimensions in vicinity of high-priority targets (U?)
4. Maximum-G turn capability of high-priority targets

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

1. Predicted locations and velocities of high-priority targets
2. Region of uncertainty for high-priority targets

Data supplied to radar as result of rule:

1. Need for additional target updates

9.7 Deterministic Maneuver Rule:

If 1) a maneuver is detected and it falls on the Position Locus Curve and the digital terrain database shows that the target must maneuver to avoid an obstacle or to approach an objective, or 2) the target is in a position for which it must maneuver along a highly-constrained path to avoid an obstacle or to reach an objective, then a deterministic maneuver term will be added in the Kalman filter to fit the target trajectory to the observed maneuver. The deterministic maneuver input will be terminated at the point at which it can no longer be certain that the maneuver will be continued.

This rule is the implementation of a technique that has been proposed in the literature for many years, but which no system has had the ability to successfully implement. (A simple example of the concept would be monitoring ship traffic in a river, where the ships *must* maneuver to follow the channel.) The KB Controller will be a suitable vehicle for testing this concept. A major problem in tracking a target that is making even a relatively low-G turn is that the filter will lag the target. If the target makes several such maneuvers in succession, the tracking filter can become unstable.

The *Maneuver Anticipation Rule* responds to an anticipated target maneuver by increasing the filter gain i.e. by favoring the radar measurements over the smoothed predictions of the target's position. The *Deterministic Maneuver Rule* adds a deterministic control to the Kalman filter. This is generally represented as **B*u** in the state prediction equation, where **B** is the transition matrix and **u** is the deterministic control, or *forcing function*. The major difference is that the Maneuver Anticipation Rule increases the size of the target acquisition window, as it cannot be certain where the target will be, while the Deterministic Maneuver Rule does not increase the size of the acquisition window, as it has a very good idea of where the target will be on the next radar scan.

For the Deterministic Maneuver Rule, if it is determined by the KB Controller that the target is making a deterministic maneuver, the tracking filter will *would back* to the point at which the maneuver was determined to have begun, the appropriate **B** and **u** values will be added to the state prediction equation and the tracking will proceed. Additionally, the amount of maneuver noise added to the filter will be reduced to only the level commensurate with the uncertainty in the maneuver.

The Deterministic Maneuver Rule will have a major impact on the system performance if it can be successfully implemented. Obviously if the direction and turn rate of the maneuver can be deduced, the area of uncertainty ellipses can be minimized. This will limit the number of samples that must be excluded when forming the sample covariance matrix. Also, for the tracker, the stability will be improved as the gain will be reduced, the probability of misassociation will be reduced and the ability to employ a LOW or VERY-LOW detection threshold will be enhanced. From a computational view point, however, the need to correlate the target position and kinematics with the digital terrain database in real-time will have a major affect on the computational requirements.

KBT / KB Controller / Radar Interfaces

Data required from KB Controller to implement rule:

1. Target priority (U)
2. Possible objective locations in vicinity of high-priority targets (U)
3. Obstacle locations and dimensions in vicinity of high-priority targets (U?)
4. Maximum-G turn capability of high-priority targets

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

1. Predicted locations and velocities of high-priority targets
2. Region of uncertainty for high-priority targets

Data supplied to radar as result of rule:

1. Need for additional target updates

9.8 Maneuver Termination Rule:

If the constant-G turn hypothesis is assumed and 1) the projection of the target track on the digital database map shows that the obstacle has been cleared or that the target is headed towards the probably objective and/or 2) the subsequent target measurement falls at or near the constant linear velocity on the Position Locus Curve, then the KBT maneuver hypothesis will be immediately terminated.

This rule is intended to quickly terminate the maneuver hypothesis when the target returns to a straight-line flight path. The criteria for terminating the maneuver hypothesis are basically the converse of those used to anticipate the maneuver. At this time, the Kalman filter is allowed to quickly reach a steady-state for a constant velocity target. This rule will benefit the STAP by providing higher-accuracy target data and conserving system resources by allowing the Kalman filter to quickly reach a steady-state condition.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Possible objective locations in vicinity of high-priority targets (U)

2. Obstacle locations and dimensions in vicinity of high-priority targets (U?)

Data required from radar to implement rule:

1. Target position and radial velocity measurements (R, θ, f_d, X, v_x, Y, v_y, z)

Data supplied to KB Controller as result of rule:

1. Predicted locations and velocities of high-priority targets

2. Region of uncertainty for high-priority targets

Data supplied to radar as result of rule:

None

9.9 Application of Maneuver Noise Rule:

If a turn is anticipated, the added maneuver noise for a Kalman filter tracker will be applied in a manner that is orthogonal to the velocity vector of the target.

For a target maneuver, the acceleration tends to be centripetal (as opposed to linear). Therefore, as a constant-G turn is the most probably target maneuver, the acceleration will be predominantly perpendicular to its velocity vector. Thus when increasing the maneuver noise to increase the Kalman filter gains, the maneuver noise will be applied so that the sum of the squares of the quantities added to the x and y-coordinate tracking filters will be a constant. The noise added to the x-coordinate tracker will be in proportion to $\sin^2\theta$ and the noise added to the y-coordinate tracker will be in proportion to $\cos^2\theta$m where θ is the angle between the velocity vector and the x-axis of a Cartesian coordinate reference system.

The impact of this rule on the KB Controller performance will be reducing the acquisition window volume when re-acquiring the target during the subsequent target update. This could provide a significant improvement in the quality of the sample covariance matrix, as fewer range-Doppler-angle cells would have to be excluded.

KBT / KB Controller / Radar Interface

Data required form KB Controller to implement rule:

1. Maximum-G turn capability of high-priority targets

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

None

Data supplied to radar as result of rule:

None

9.10 Linear Acceleration Rule:

If a detection occurs in the maneuver gate and a detection does not occur in the non-maneuver gate and the detection lies *close* to a straight line projection of the existing target track, then it will be assumed that the target is accelerating linearly. For a Kalman filter tracker, maneuver noise will be added to the along-track component of the target's velocity state vector.

The purpose of this rule is to avoid adding maneuver noise to the cross-track velocity state vector when no acceleration in this dimension is being observed. When a detection occurs outside the non-maneuver gate *but* is very close to the projected flight path, it is reasonable to assume that the target is rapidly accelerating or decelerating. The filter must respond to this change in speed, but should not increase the filter gain in the cross-track dimension.

When increasing the maneuver noise to increase the Kalman filter gains for a linear acceleration, the maneuver noise will be applied so that the sum of the squares of the quantities added to the x and y-coordinate tracking filters will be a constant. The noise added to the x-coordinate tracker will be in proportion to $\cos^2\theta$ and the noise added to the y-coordinate tracker will be in proportion to $\sin^2\theta$, where θ is the angle between the velocity vector and the x-axis of a Cartesian coordinate reference system.

This rule will benefit STAP by providing higher-accuracy target data and conserving system resources by not pursuing the constant-G turn flight path hypothesis when the maneuver detector is activated.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Maximum acceleration/deceleration rate of high-priority targets

Data required from radar to implement rule

None

Data supplied to KB Controller as result of rule:

None

Data supplied to radar as result of rule:

None

9.11 Threshold Bias Consideration Rule:

If the clutter residue level in the CFAR processor increases by an amount sufficient to cause a missed detection (based on the mean and standard deviation of the signal-to-noise ratio SNR for the target on previous observations), and if there is no reason to assume that a target maneuver has occurred (i.e. there are no radar detections in proximity to the acquisition gate), then coast the target track through the clutter region and DO NOT demote the track state if not required by the Track State Promotion Logic Rule.

Missed detections can occur if the clutter residue is too large to provide an adequate signal-to-clutter ratio (SCR), even if there is an adequate signal-to-noise ratio (SNR). The SNR for a target will, in general, not change dramatically from scan-to-scan for a typical aircraft target, and especially not for a LO target, if the aspect angle does not change dramatically.

The issue to be addressed by this rule is that the KB Controller might unnecessarily devote resources by assuming that a target has been lost or that a maneuver has occurred, when in fact it is more probable that local interference (strong clutter, ground traffic, etc.) is the cause of the difficulty. This can be a major problem when radar's resources are being taxed by having to track multiple, high-priority LO targets.

The KBT will make use of: 1) the radar's clutter map to determine if the CFAR threshold has increased significantly versus the previous observation, 2) a digital terrain map to determine if there exists strong clutter, highway traffic, etc. and 3) knowledge of the target to determine if there is more evidence supporting a maneuver hypothesis and the local environment or the continuation of a straight-line flight path.

The rule will be applied only if the track state logic does not require that the track state be demoted. In some cases, if a track coasted for too long a period of time, it will become improbable that the target can be re-acquired because of the age of the information used to project the track. In such cases, the track state demotion logic will override this rule.

The impact of this rule on the radar will be that a larger volume may have to be searched for a target after it can again be viewed by the radar. This will require the use of more system resources. However, if the necessity to re-identify high-priority targets can be avoided, a net performance gain for the overall system should be achieved.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)
2. Severe clutter conditions exist (optional)
3. Jamming exists (optional)

Data required from radar to implement rule:

1. Detection threshold
2. Clutter map / Absolute CFAR threshold level (optional)

Data supplied to KB Controller as result of rule:

1. Track state

Data supplied to radar as result of rule:

1. Need for additional high-priority target updates
2. Need for extended high-priority target dwells

9.12 Clutter Censoring Rule:

A map of clutter *discretes* will be maintained by the KB Controller. If a detection occurs in a range-Doppler cell for which a discrete is known to exist, that detection will be censored by the KBT. The discrete can be in either the mainlobe or the sidelobes of the radar's antenna pattern.

The purpose of this rule is to reject false detections due to stationary ground targets having very large radar cross sectional (RCS) areas (e.g. 50 dBsm or more). The locations of the discretes will be determined from the digital terrain database, and verified by the radar clutter map. The discretes can either fall in the mainlobe or the sidelobes of the antenna pattern. Mainlobe discretes are typically rejected by the radar's MTI and Doppler frequency filtering. Discretes in the skirts of the mainlobe or in the sidelobes will have Doppler frequencies similar to actual targets, and cannot be rejected in this manner.

For discretes outside of the mainlobe of the radar beam, the KB Controller will maintain a file of ranges and angles. Maintaining this file will allow the (possibly ambiguous) Doppler frequency of the discrete's radar return to be determined. This data will be used by the KBT to determine which threshold crossings to censor.

The incorporation of a technique for censoring the discretes will be a major benefit for the KBT, especially when LO targets are being tracked. Because of its large RCS, a sidelobe discrete can easily be confused with a LO target threshold crossing. By censoring the range-Doppler cells containing the discretes, there should be a significantly lower number of false detections, track bifurcations and false tracks. This, in turn, should allow a much more efficient utilization of the radar resources.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Discrete locations (x, y) (U)

Data required from radar to implement rule:

1. Clutter map / Absolute CFAR threshold level (optional)

Data supplied to KB Controller as result of rule:

None

Data supplied to radar as result of rule:

1. Need for additional target updates

9.13 Ground Traffic Rule for Single, Low Degree-of-Freedom (DOF) STAP Algorithm and Low PRF Radar Waveform:

If a *major* road exists in the mainlobe of the antenna pattern and a detection occurs at that location and it is at an absolute velocity relative to the radar of ≤35*cos(ρ) m/s, where ρ is the angle between the radar line-of-sight (LOS) vector and the road, then this detection will be assumed to be corrupted by ground traffic and will be censored by the KBT.

A low DOF STAP system will rely principally on the two-way sidelobes of the antenna pattern to reject radar returns from ground traffic outside of the radar mainlobe. Traffic returns that fall within the mainlobe will complete with air targets whose Doppler frequency are low or are ambiguously sampled. Ground traffic returns can range over nominally ±35 m/s for major highways. The velocity of the traffic as seen by the radar is a function of cos (ρ). This reduces the speed of the ground traffic as seen by the radar as the road becomes perpendicular to the radar's LOS vector.

It will probably be necessary to censor all filters that correspond to Doppler frequencies within the range of ≤35*cos(ρ) m/s, as bends in the road, accelerating and decelerating traffic, normal speed variations, etc. can provide ground target returns for virtually all speeds. Thus only the Doppler filters centered about PRF/2 may be usable by the KBT, and then only for low-frequency (i.e. UHF or L-band) radars.

The principal impact of this rule on the KBT will be *troublesome* regions for which many false detections can exist will be censored, which will greatly reduce the number of misassociations, bifurcations and false track initiations. The secondary effect will be that existing tracks must be coasted through these regions.

A concept that could be used, especially in a relatively wide bandwidth (e.g. 5 MHz) radar, is to maintain a radar detection map (as opposed to a full-up tracker) in highway regions. A ground target will travel a maximum of nominally 450 m between radar dwells. Thus, if long stretches of road are visible, but the traffic density is light (e.g. operation at night, over Montana, etc.), a cell would not be censored if it was more than 450 m from a threshold crossing at a road location on the previous scan. In such a case, the velocity of the detection on the previous scan might also be considered if this data is available. The detection location for the subsequent scan would be projected by the KB Controller, which has knowledge of the road location and curves, ground traffic LOS visibility, etc., as opposed to the KBT, which does not have this information.

KBT / KB Controller/Radar Interface

Data required from KB Controller to implement rule:

1. Road locations (x, y, ρ) (U?)

Data required from radar to implement rule:

1. Radar frequency, PRF and Doppler filter bandwidth

Data supplied to KB Controller as result of rule:

None

Data supplied to radar as result of rule:

None

9.14 Ground Traffic Rule for Multiple STAP Algorithms and Medium/High PRFs:

For this rule, a *low velocity target* is defined as a target whose *radial* velocity (i.e. v*cos ρ) is similar to that of ground traffic (e.g. ±35 m/s); a *high velocity target* is defined as a target whose velocity exceeds that of ground traffic but is less than the velocity of the radar platform; a *very-high velocity target* is defined as a target whose velocity is greater than the velocity of the radar platform.

Case 1:

If the target velocity is LOW and the competing ground traffic is in the mainlobe of the radar, then: 1) a track will not be initiated if a road is present at or near the threshold crossing location, 2) an existing track will be coasted and the track state will not be reduced if a detection is not made and 3) conventional processing (as opposed to STAP) will be recommended unless other considerations prevail.

Case 2:

If the target velocity is LOW and the competing ground traffic is in the sidelobes of the radar, then: 1) a medium or high PRF waveform will be recommended, and 2) a STAP algorithm that can perform sidelobe nulling to reject clutter and sidelobe ground traffic will be recommended.

Case 3:

If the target velocity is HIGH and the competing ground traffic is in the mainlobe of the radar, then: 1) a medium or high PRF waveform will be recommended, and 2) a STAP algorithm that can reject the sidelobe ground clutter at the same Doppler frequency as the target will be recommended.

Case 4:

If the target velocity is HIGH and the competing ground traffic is in the sidelobes of the radar, then: 1) a medium or high PRF waveform will be recommended, and 2) a STAP algorithm that can perform sidelobe nulling to reject both the ground clutter and the ground traffic will be recommended.

Case 5:

If the target velocity is VERY HIGH, then conventional will be recommended unless other considerations prevail.

Ground traffic can be a principal cause of false detections in the radar system. The KBT will be able to deal with ground traffic by predicting its location from digital databases and radar clutter maps. The KBT design will attempt to avoid *brute force* approaches such as blanking ranges and Doppler frequencies where ground traffic returns are severe. By accurately predicting the location of the target at each update, assessing the local environment prior to the

radar observation and selecting the optimal waveform/STAP algorithm combination, a significant performance improvement can result.

The location of roads will be determined from either or both the radar clutter map and the digital terrain database. The radar waveform must be considered by the KB Controller to determine if range ambiguities (and to a lesser extent the Doppler ambiguities) will impact the detection/tracking performance.

The purpose of the Case 1 rules is to avoid an extreme number of false track initiations due to road traffic. It would obviously be preferable to delay the target update until the ground traffic is no longer in the mainlobe; however this is often impractical, and is generally impossible in a mechanically scanned antenna. Coasting the track through such locations is recommended for the tracker design. Conventional processing will probably suffice in this situation, as the target cannot be separated from the ground traffic by either spatial or Doppler filtering. Note that if the ground traffic had the same Doppler frequency as the target and if the ground traffic returns were included in the sample covariance matrix, then a mainlobe null would be formed that would serve to cancel the target return.

Case 2 exists because, even though ground traffic in the sidelobes is attenuated by the two-way antenna pattern, the radar cross-section (RCS) of large numbers of vehicles (especially trucks) can be large enough to compete with LO target returns. This is because the Doppler frequencies of these vehicles will be offset by the Doppler frequency caused by the radar platform's motion. Under Case 2 spatial filtering will be effective, whereas Doppler filtering/temporal degrees-of-freedom probably will not. A waveform that does not create Doppler ambiguities is recommended; else the STAP algorithm must create multiple nulls, one for each ambiguous Doppler frequency that equals the target's Doppler frequency. A consideration with such a waveform is that range-ambiguous ground traffic returns may compete with the target return if a poor choice of the PRF is made.

In Case 3, Doppler processing will separate the target and the ground clutter, provided the PRF is sufficiently high as to prevent a Doppler ambiguity in the target return. STAP would be used to null sidelobe clutter at the target's Doppler frequency. The choice of the STAP algorithm would be made by the KB Controller.

In Case 4, the target and the ground traffic can again be the same Doppler frequency. A spatial null would probably be required to reject the ground traffic return, and the STAP algorithm must be chosen accordingly.

Finally, in Case 5 it may not be desirable to use STAP if the tracker can ensure with a reasonably-high degree of confidence that the Doppler frequency of the target will exceed the highest possible ground traffic Doppler frequency. The *worst case* will be a function of the target velocity, the ground traffic velocity and the angular separation of their returns. This rule will have a key impact on the KB Controller design. The presence of ground traffic is viewed as probably being one of the most difficult environmental factors to be addressed in LO detection, especially if minimal weighting is used on the transmit antenna to maximize the output power. The KBT performance will be severely degraded if a large number of false targets are reported,

as the system resources will be overly taxed, many false tracks could be spawned, incorrect data-to-track associations will occur, etc. information.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Road locations (x, y, ρ) (U?)

Data required from radar to implement rule:

1. Radar frequency, PRF and Doppler filter bandwidth

Data supplied to KB Controller as result of rule:

None

Data supplied to radar as result of rule:

1. Need for additional target updates

9.15 Track Bifurcation Rule:

Track bifurcation will be a function of the target priority, the number tracks that are being maintained and the available system resources. The system controller will assess the available resources and establish the target priority for which bifurcation will be allowed to occur. Tracks will only be bifurcated if the Priority ≥1 unless a *significant* excess in system resources exists. Additionally, a track will not be bifurcated if another sensor provides a report that correlates with the non-maneuvering target track hypothesis.

Under normal conditions, if a detection falls inside the maneuver gate and there is no detection in the non-maneuver gate and the Priority ≤0, the KBT will re-initialize the target track.

Track bifurcation, or the spawning of multiple tracks from a single track, can occur for several reasons, among which are:

1. Multiple detections occur in the data-to-track association window.

2. For a HIGH-PRIORITY (e.g. Priority =1 and Track State = S3 or Priority = 2 and Track State = S3 or M1) or a VERY-HIGH-PRIORITY (e.g. Priority = 3 and Track State = S3 or M1) target, a detection occurs in the maneuver window and no detection occurs in the non-maneuver window.

3. For a VERY-HIGH-PRIORITY target, a detection occurs in both the maneuver and the non-maneuver windows.

(NOTE: This rule must be refined to determine the impact of the threshold level on the KBT performance. For example, given that the detection in the maneuver window occurs at the NORMAL threshold, should a detection at the LOW or the VERY-LOW threshold in the limited-volume non-maneuver window override the other, or should the track be bifurcated? This will have an impact on the STAP, as it may be necessary to reprocess the data to form sample covariance matrices with different samples excluded to test at the LOW and the VERY-LOW threshold levels. This is because the search volume using the LOW/VERY LOW threshold could be smaller than for the NORMAL threshold.)

If is not desirable to bifurcate tracks, as the multiple hypotheses will consume valuable system resources and can cause significant confusion in the tracker. Therefore, only high-priority target tracks will be bifurcated; the conventional wisdom being that it is better to assign detections to existing tracks, spawn new tracks with the detection residues and re-establish or link the old and new tracks at a later time than to sort out a maze of alternative track hypotheses. The data-to-track association will be accomplished for the non-bifurcated tracks by a technique such as Probabilistic Data Association (PDA), which minimizes the mean-square error in the data assignments.

If other sensors such as ESMs or off-board radar reports are operating in concert with the radar under KB Control and they supply a real-time report that correlates with the non-

maneuvering hypothesis, this will be considered sufficient cause to negate the maneuvering target hypothesis.

The concept of reinitializing tracks when a detection occurs in the maneuver gate and the data-to-track assignment logic assigns that detection to an existing track is a common design practice. It avoids the difficulty in stabilizing the Kalman filter (if one is being used) and the possibility of oscillations in the tracker. This technique will conserve system resources.

The impact of the Track Bifurcation Rule on the KB Controller will be considerable, as each bifurcated track could have unique STAP requirements. Therefore, the processing load could increase significantly, and under conflicting operational requirements could result. In case of a conflict, the KB Controller should first give precedence to the track with the greatest credibility (e.g. the one avoiding an obstacle or heading towards a logical objective), and then to the track with the highest Track State (i.e. the one closest to S3).

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)
2. Detection reports from other sensors (U)

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

1. Number of bifurcated target tracks for high-priority targets
2. Predicted locations and velocities of high-priority targets
3. Regions of uncertainty for high-priority targets
4. Track states

Data supplied to radar as result of rule:

1. Need for additional target updates

9.16 Bifurcated Track Termination Rule:

If track bifurcation occurs, the bifurcated tracks will each be subjected to the Track State Promotion Logic for the given target priority. This will allow conditions such as a missile being launched from an aircraft to be addressed with no modification of the tracking logic (the presence of two confirmed targets must be acknowledged by the system if both tracks attain the CONFIRMED track state). A bifurcated track can be terminated by the KBT if the Track State of the alternative hypothesis is at least two states higher (e.g. one path is in state S3 while the other is in state M2).

A bifurcated track can be quickly terminated or assigned a lower target priority by the KB Controller if that track is *illogical* or non-threatening (e.g. it is on a collision course with an obstacle or it is exiting the region of the critical objectives being defended with the radar). The maneuvering hypothesis track could also be terminated if a NORMAL threshold occurs on the subsequent scan in the non-maneuver window. In this case, the detection made in the maneuver window would be subjected to the normal track initiation logic. If assigned a lower priority the target would, for example, be processed with an $\alpha\beta$ tracker and not considered by the KB Controller for exclusion from the sample covariance matrix.

Finally, if the KB Controller can receive data from other sources, it could request data to support one or the other of the track hypotheses.

As stated in the Track Bifurcation Rule, it is not desirable to maintain bifurcated tracks, as they consume valuable system resources and can cause significant confusion in the tracker. For these reasons, only high priority target tracks will be bifurcated. The KBT problem, however, is that if a high-priority, LO target track is lost, both the track and the associated target priority must be re-established. For this reason, bifurcation will be performed when Priority$\geq$1, assuming the radar computational resources are available. Allowing the bifurcated tracks to be resolved by demotion in the track state is methodical but slow; too many system resources may be ineffectively used while the track bifurcation exists. The KBT alternatives for this rule are to terminate one track or to reduce its priority if:

1. Its track state is at least two below the alternative hypothesis.

2. Its path is illogical or non-threatening.

3. A NORMAL threshold level detection occurs for the non-maneuvering track hypothesis on the next scan.

4. A hypothesis is confirmed by another (surrogate) sensor

In all of these cases, the discarded track data should be tested by the track state logic to determine if it meets the criteria for establishing a new track.

Conversely, should both tracks continue to exist after N radar dwells (where N is TBD, but will probably be on the order of three to five), then two target tracks having the same priority

will be assumed to exist. For example, an attack aircraft could have launched a missile and is locking it onto its objective.

The impact of the Bifurcated Track Termination Rule on the KB Controller are the same as for the Track Bifurcation Rule.

KBT / KB Controller / Radar Interface

Date required from KB Controller to implement rule:

1. Target priority (U)
2. Possible objective locations in vicinity of high-priority targets (U)
3. Obstacle locations and dimensions in vicinity of high-priority targets (U?)
4. Detection reports from other sensors (U)

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

1. Number of bifurcated target tracks for high-priority targets

Data supplied to radar as result of rule:

1. Need for additional target updates

9.17 LOW/VERY-LOW Threshold Window Size Rule:

The acquisition window size for the LOW and the VERY-LOW thresholds will produce a probability of false alarm ≤ 0.1 per window. (NOTE: THE VALUE 0.1 IS TENTATIVE; IT WILL BE REFINED BY EXERCISING THE KBT SIMULATION.)

This rule may be terminated if the interference is too severe (e.g. if it is influenced by jamming, strong non-homogenates, temporal variations, etc.).

The purpose of this rule is to ensure that the KBT does not generate false tracks by following a sequence of false alarms. The risk in reducing the detection threshold is obviously that a greater number of false alarms will occur. This effect can be compensated in specific cases by limiting the number of test cells to which the reduced threshold is applied. Thus, for example, if the probability of false alarm were 10^{-4}, but if the threshold were applied to only 1,000 test cells, there would be (on average) only one false alarm for every ten radar dwells. Assuming that reducing the detection threshold results in several additional radar detections of the target, the net improvement in the tracker performance should be significant.

This rule could have a significant impact on the KB Controller, as it would have to determine the lower detection threshold value for the KBT. It may also be necessary to reprocess the radar data to form sample covariance matrices with different samples excluded. This is because the search volume using the LOW/VERY LOW thresholds will be smaller than for the NORMAL threshold. The sample covariance matrices should be of higher quality, however, as a larger number of clutter samples taken in proximity to the target will be available for its formation.

It is felt that this rule should not be applied under extreme interference conditions, as the probability of a false alarm may become much higher than desired if the detection threshold is reduced.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Sever Clutter conditions exist (optional)
2. Jamming exists (optional)

Data required from radar to implement rule:

1. Clutter map / Absolute CFAR threshold level (optional)

Data supplied to KB Controller as result of Rule:

None

Data supplied to radar as result of rule

1. Acceptable probability of false alarm

9.18 LOW Threshold Maneuver Gate Size Rule:

If a detection is only made in the maneuver gate with the LOW threshold and if the non-maneuver gate has no conditions that would prohibit a target detection and if the system resources are adequate, then for the subsequent scan:

1. **The maneuver gate size for this track will expand as if a detection *had not* been made and the NORMAL threshold will be used.**

2. **The maneuver gate size for this track will expand as if a detection *had* been made and the LOW threshold will be used.**

If the system resources are adequate to perform both parts of this rule, then only Part 2 of this rule will be applied.

Even though the probability of a false alarm in the maneuver gate will be low (probably ≤ 0.1), it will still be large enough that there will be a significant chance that the target was in the maneuver gate, but was not detected at the lower threshold. If a false alarm also occurred, the maneuver gate on the following scan could be positioned and dimensioned so that the true target would fall outside of its boundaries and not be associated with the target track.

The minimize the chance of such an event, the KBT will test both these hypotheses. The LOW threshold will only be applied to the maneuver gate projected by the LOW threshold crossing on the previous scan if it is again utilized.

The application of this rule could have a significant impact on the KB Controller and STAP processing. The increased volume of the maneuver gate will require that a much larger number of cells be excluded from the sample covariance matrix formation. Also, multiple beam positions may have to be considered to locate the target. Thus, if the system resources are being heavily taxed, the system controller should not test Part 1 of the rule and act on the LOW threshold detection.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)

2. Maximum-G turn capability of high-priority targets

3. Maximum acceleration/deceleration rate of high-priority targets

Data required from radar to implement rule:

1. Measurement accuracies (ΔR, $\Delta\theta$, Δf_d)

Data supplied to KB Controller as result of rule:

1. Number of bifurcated target tracks for high-priority targets

2. Predicted locations and velocities of high-priority targets

3. Region of uncertainty for high-priority targets

4. Track state

Data supplied to radar as result of rule:

1. Need for additional target updates

9.19 Track State Promotion Logic (TSPL) Assignment Rule:

The TSPL for each target will be assigned as a function of the target's priority and the available processing resources. For the TSPLs shown in Tables TSPL-1 through 4, the following assignments will be used:

TSPL	**Target Priority**
Low	**≤-1**
Mid	**≥0**
High	**≥1**
Very-High	**=3**
T-B-D	**≥2**

The T-B-D TSPL will run in parallel with the High-priority TSPL and will be applied only to targets that are not expected to maneuver.

The TSPLs for the KBT are shown in Tables TSPL-1, 2, 3, and 4. In all cases, S3 is the CONFIRMED track state. The M-states (i.e. the missed detection states) can be entered only after the S3 state has been attained. The M1 state is also considered to be a CONFIRMED track state when applying the LOW or the VERY-LOW detection threshold.

The Low-Priority TSPL logic requires two consecutive detections *after the initial detection* without having two consecutive missed detections for track initiation, and N-of-3*(N-2) where N≥3, missed detections for track deletion. (Note that a Low Priority target can usually be tracked by an IFF or secure data link, and therefore using radar assets to maintain a track is generally not warranted.) The Mid and High-Priority TSPLs requires N-of-(2N-1), where N≥2, consecutive detections *after the initial detection* without having two consecutive missed detections for track initiation. They also require an N-of02(N-2), where N≥3, missed detections for track deletion. Note, however, that the detection threshold and whether the target is detected in the non-maneuver gate or the maneuver gate is now considered in the TSPL. Testing at the LOW THRESHOLD is not done until at least two detections have been made at the NORMAL threshold level.

For the Very-High-Priority TSPL, an N-of-2N logic is used *after the initial detection* and to initiate the track, with the LOW THRESHOLD also being tested in the non-maneuver gate if two consecutive detections are made. The logic for dropping the track is more complex and is somewhat more susceptible to false detections, however it should help the KBT to maintain track on CONFIRMED hostile targets.

The Track-Before-Detect (T-B-D) TSPL is intended to maintain a track on a non-maneuvering, high-priority target for which the probability of detection is low (e.g. $P_d \leq 0.5$). It is initiated only after Track State S3 is attained, and is run in parallel with the Very-High-Priority

TSPL. The T-B-D is intended to continue tracks even when the target goes undetected for a substantial period of time. The T-B-D processing will not delete a track unless it goes undetected on eight or more of the previous ten target dwells, which allows the target track to be maintained for non-detection intervals well in excess of one minute, as opposed to the nominal 30 to 40 seconds for the high-priority TSPL. (NOTE: Work will be required to test both the Very-High-Priority and the T-B-D TSPLs.)

For some operating conditions and from the generation of other rules it has been determined that the track state will not be demoted, even though there is a missed detection under conditions such as the following:

1. The target is masked by the intervening terrain
2. The detection threshold is raised due to jamming or strong clutter residue
3. Ground traffic returns or discretes prohibit reliable target detections
4. The target motion is tangential to the radar
5. A strong multipath fade zone is known to exist
6. A range and/or velocity blind condition exists

The conditions listed above are shown as being optional in the interface description provided below. This is because the ability of the radar to detect the target may be determined by the KB Controller, and simply passed as a visible/not visible flag to the KBT.

The Track State Promotion Logic Assignment Rule will require an interface with the KB Controller, as it requires knowledge of the target's priority. This rule will have minimal direct impact on the KB Controller's performance, although indirectly it will have a significant impact on the utilization of the system resources.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)
2. Target visibility (U?) (optional)
3. Road locations (x, y, ρ) (U?) (optional)
4. Discrete locations (x, y) (U) (optional)
5. Detection reports from other sensors (U) (optional)
6. Range or Doppler blind condition exists (optional)
7. Severe clutter conditions exist (optional)

8. Jamming exists (optional)

9. Multipath fade zone exists (optional)

Data required from radar to implement rule:

1. Clutter map / Absolute CFAR threshold level (optional)

Data supplied to KB Controller as result of rule:

1. Track state

Data supplied to radar as result of rule:

None

Table TSPL-1: Low-Priority Target Track State Promotion Logic

			OBSERVATION RESULT				
TRACK STATE	Miss		Hit (N/N)	Hit (N/M)	Hit (L/N)	Hit (L/M)	(Hit) (VL/N)
S0	S0		S1	N/A	N/A	N/A	N/A
S1	S0		S2	N/A	N/A	N/A	N/A
S2	S1		S3	N/A	N/A	N/A	N/A
S3	M1		S3	S3	N/A	N/A	N/A
M1	M2		S3	M1	N/A	N/A	N/A
M2	S0		M1	M2	N/A	N/A	N/A

Table TSPL-2: Mid-Priority Target Track State Promotion Logic

			OBSERVATION RESULT				
TRACK STATE	Miss		Hit (N/N)	Hit (N/M)	Hit (L/N)	Hit (L/M)	(Hit) (VL/N)
S0	S0		S1	N/A	N/A	N/A	N/A
S1	S0		S2	N/A	N/A	N/A	N/A
S2	S4		S3	N/A	N/A	N/A	N/A
S3	M1		S3	S3	N/A	N/A	N/A
S4	S0		S3	N/A	N/A	N/A	N/A
M1	M2		S3	M1	N/A	N/A	N/A
M2	S0		M1	M2	N/A	N/A	N/A

Note: In the above tables, the quantity in parenthesis under Hit denotes (Threshold/Association Gate), where for Threshold: N = Normal, L = Low and VL = Very-Low, and for association Gate: N = Non-Maneuver and M = Maneuver

Note: N/A denotes this threshold/gate pairing is not applicable.

Table TSPL-3: High-Priority Target Track State Promotion Logic

			OBSERVATION RESULT				
TRACK STATE	Miss		Hit (N/N)	Hit (N/M)	Hit (L/N)	Hit (L/M)	(Hit) (VL/N)
S0	S0		S1	N/A	N/A	N/A	N/A
S1	S0		S2	N/A	N/A	N/A	N/A
S2	S4		S3	N/A	S3	N/A	N/A
S3	M1		S3	S3	S3	N/A	N/A
S4	S0		S3	N/A	S3	N/A	N/A
M1	M2		S3	M1	M1	N/A	N/A
M2	S0		M1	M2	M2	N/A	N/A

Table TSPL-4: Very-High-Priority Target Track State Promotion Logic

			OBSERVATION RESULT				
TRACK STATE	Miss		Hit (N/N)	Hit (N/M)	Hit (L/N)	Hit (L/M)	(Hit) (VL/N)
S0	S0		S1	N/A	N/A	N/A	N/A
S1	S4		S2	N/A	N/A	N/A	N/A
S2	S5		S3	N/A	S3	N/A	N/A
S3	M1		S3	S3	S3	N/A	S3
S4	S0		S2	N/A	N/A	N/A	N/A
S5	S4		S3	N/A	N/A	N/A	N/A
M1	M2		S3	M1	S3	M1	M1
M2	S0		S3	M2	M1	M2	M2

Note: In the above tables, the quantity in parenthesis under Hit denotes (Threshold/Association Gate), where for Threshold: N = Normal, L = Low and VL = Very-Low, and for association Gate: N = Non-Maneuver and M = Maneuver

Note: N/A denotes this threshold/gate pairing is not applicable.

Table TSPL-5 Track-Before-Detect (T-B-D) Logic

1. The Target Priority must be 3 and the Track State must be S3 to initialize the T-B-D.

2. The KB Controller must indicate that there is a high probability that the target will continue along a straight-line flight path for several minutes (i.e. there are no obstacles or probable objective in proximity to the current target location).

3. Only the Non-Maneuver data-to-track association gate will be used. This gate will be expanded if detections are missed to account for a maximum target centripetal acceleration of 0.1 Gs (i.e. 1 m/s^2). No linear acceleration will be assumed. The Singer model will be used for adding maneuver noise to the Kalman filter.

4. The detection threshold will be set at a level for which the cumulative probability of false alarm is same as for the conventional radar system. (The detection threshold for T-B-D processing will be a function of the M-of-N rule, the window growth rate, the maximum target maneuver, etc. It is typically about a dB lower than for the conventional radar processing.) Reference: T-B-D Development and Demonstration Program, Phase II Final Technical Report, RADC-TR-86-68, May 1986, pg 41.

5. The track will be continued if the target is detected on any three of the most recent ten radar dwells.

6. If multiple detections occur in the track association window, the one having the minimum distance to the existing track will be associated with the track.

9.20 Track State Coasting Rule:

The maximum number of consecutive radar dwell periods (e.g. scans) that a track state will be coasted without demoting the track state will be a function of the target priority. Unless there is data from other sensors to support the track when the target is not visible to the radar, the maximum number of coasted scans will be:

Target Priority	**Number of Coasted Scans**
≤0	**1**
1 or 2	**2**
3	**3**

The coasting of the low-priority targets assumes that sufficient system resources are available.

Even if the target whose Priority is ≥1 is demoted to Track State S0, its track will be maintained and it will be tested after it again becomes visible to the radar. If the target is re-acquired within a constrained-size non-maneuver data-to-track association window after being coasted, then the track will be re-instated and its state will be promoted to a level corresponding to that for which NO DEMOTION had occurred.

Track coasting, i.e. not demoting a track even though a detection report is not received, will be applied in cases for which it is reasonable to assume that the radar could not detect the target. Causes of this condition include:

1. Terrain obscuration
2. Severe clutter
3. Ground traffic
4. Discretes
5. Multipath fading
6. Jamming
7. Blind ranges and/or velocities
8. Tangential target velocities

The conditions listed above are shown as being optional in the interface description provided below. This is because the ability of the radar to detect the target may be determined by the KB Controller, and simply passed as a visible/not visible flag to the KBT.

The problem with coasting target tracks is that after several consecutive scans without a detection report, the volume of the data-to-track association window can become extremely large. This makes it extremely difficult to accurately assign detection reports to existing tracks, as several combinations may be possible and the PDA evaluation criteria do not provide clear choices. The KBT, however, is faced with the challenge of re-establishing both the track and the target priority if the track is lost.

If sufficiently-accurate (surrogate) data is available from other sensors, track coasting can be maintained for a significant period of time. Otherwise, the maximum number of coasted scans will be limited by this rule.

It is conceivable that a target that might have been in track state S3, for example, could have been demoted twice although the KBT knows that it was masked by terrain or jamming, etc. In such a case, the KBT will continue the track; however, it will constrain the growth of the data-to-track association window (which could otherwise become quite large). If the target is detected within that window on the next opportunity after it can again be viewed by the radar, its track will be restored as if no demotion had occurred.

The Track State Coasting rule requires that the KB Controller use a considerable portion of its resources to ensure that the target is indeed obscured to the radar. The KB Controller must determine that at least one of the items listed above is most probably causing the target to go undetected. Because of this resource utilization, low priority targets are only coasted for a single scan before demotion begins, and then only if the available assets permit the evaluation. The benefit will be in not having to re-establish the track on the high-priority target is a successful data-to-track association can be made when it again becomes visible to the radar.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)
2. Target visibility (U?) (optional)
3. Road locations (x, y, ρ) (U?) (optional)
4. Discrete locations (x, y) (U) (optional)
5. Detection reports from other sensors (U)
6. Range or Doppler blind condition exists (optional)
7. Severe clutter conditions exist (optional)
8. Jamming exists (optional)
9. Multipath fade zone exists (optional

Data required from radar to implement rule:

1. SNR of detection
2. Detection of threshold
3. Target position and radial velocity measurements (R, θ, f_d, x, v_x, y, v_y, z)
4. Measurement accuracies (ΔR, $\Delta\theta$, Δf_d)
5. Clutter map / Absolute CFAR threshold level

Data supplied to KB Controller as result of rule:

1. Track state

Data supplied to radar as result of rule:

1. Need for additional target updates

9.21 Tracker Type Assignment Rule:

The type of tracker assigned for each target will be a function of the high priority of that target and of the available system resources. If the system resources DO NOT cause a limitation, the following assignments will be used.

Tracker Type	Target Priority	Radar PRF
$\alpha\beta$Filter	**≤ 0**	**Low**
$\alpha\beta\lambda$ Filter	**≤ 0**	**High**
Kalman Filter	**≥ 1**	**Low**
Extended Kalman Filter	**≥ 1**	**High**

Additionally, if it is seen that another target will cross the path of a high-priority target and sufficient computational resources exist, the KBT may apply a Kalman filter to the crossing target to minimize the chance of misassociating the two targets after their paths cross.

The objective of providing multiple tracker types in the KBT is to allow the system controller to have several options available to address different target density and target priority scenarios. The $\alpha\beta$ and the $\alpha\beta\lambda$ filters will be used against low priority targets, where STAP will usually not be required and the occasional loss of track is not a serious issue. The $\alpha\beta\lambda$ filter, which uses the target acceleration estimate, is compatible with a radar having a high PRF waveform.

The Kalman filtering will be used primarily against high-priority, LO targets, although if computational resources are available, it will be possible to use them against lower priority targets. The extended Kalman filter uses the Doppler frequency data to estimate the target velocity, which requires a non-linear transform to model in the filter.

Applying a Kalman filter to a high-priority LO target will minimize the chance that the returns from the two targets will be misassociated when a crossing occurs. **An interesting experiment would be to generate a crossing scenario and process it using various STAP techniques, with the quality of the tracks supplied by the KBT being an experimental variable.**

The Tracker Type Assignment Rule will require a significant amount of interaction with the KB Controller, as the controller must dynamically allocate the tracker resources. It is envisioned that tracks could be switched from a Kalman to an $\alpha\beta$ filter, or vice-versa, as the system loading varies.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

1. Predicted locations and velocities of high-priority targets
2. Region of uncertainty for high-priority targets

Data supplied to radar as result of rule:

None

9.22 ESA Control Rule:

The KBT can request additional CPIs during a target dwell if a threshold crossings does not occur under the following conditions:

One Additional CPI if:

Target Priority = 3 and Track State = S3

Target Priority = 2 and Track State = M1

Target Priority = 1 and Track State = M2

Two Additional CPIs if:

Target Priority = 3 and Track State = M1 or M2

Target Priority – 2 and Track State = M2

Three Additional CPIs will be terminated if a threshold crossing occurs.

The KBT can request additional target dwells under the following conditions:

Target Priority = 3 and a LOW threshold crossing occurs in the maneuver gate

Target Priority ≥1 and a NORMAL threshold crossing occurs in the maneuver gate

The Target Priority = 3 and the Track State = M1

The Target Priority ≥1 and the Track State = M2

The KB Controller will allocate such additional dwells based on the overall system requirements.

The purpose of this rule is to allow the KBT to request additional target data under stressing conditions. In the case of requesting additional CPIs, it is assumed that the radar can rapidly process the data and quickly revisit the predicted target location. (Obviously there may be a short time interval between the CPIs, as the STAP processor and the radar beam controller will take some time to process the data and position the beam.) However, due to the critical nature of CONFIRMED HOSTILE targets, as well as of POSSIBLE and PROBABLE HOSTILE, and due to the difficulty in re-establishing track and target priority, a quick response to a *no detection* condition is warranted.

The requesting of additional radar dwells will occur if the Track State is ≤ S3 or if the KBT observes that the target is maneuvering. Under these conditions, if the radar resources allow, a more frequent update rate of the most critical targets is a very judicious decision. Coverage in an area where few detections have been made or in which no high-priority targets

exist can usually be sacrificed, or fewer CPIs per dwell and/or shorter CPIs can also be used to make up the radar time-line.

The ESA Control Rule will have a significant impact on the KB Controller configuration if such a system were to be implemented. Indeed, this could be *the* most stressing task for the decision logic. Also, the antenna beam controller speed and flexibility would have to be designed to accommodate the beam switching speeds and agility required. This rule would also impact the KBT, as it would have to predict where the target would be at the time when the KB Controller allocates the additional radar CPIs and/or dwells.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U)

Data required from radar to implement rule:

None

Data supplied to KB Controller as result of rule:

None

Data supplied to radar as result of rule:

1. Need for additional target updates
2. Need for extended target dwells

9.23 Data-to-Track Association Window Dimension Rule:

The non-maneuver data-to-track association window will be an (hyper-) ellipsoid having an axis half-length of 3σ, where σ is the standard deviation of the target measurement parameter corresponding to that axis. Position accuracy (σ_x, σ_y) will always be included. To enhance the data-to-track association in the KBT, the window can also have dimensions based on velocity (σ_{vx}, σ_{vy} if the target's Doppler frequency is measured, the target's altitude (σ_H) if elevation angle is measured, and/or the target's Radar Cross Section (σ_{RCS}) as determined from the SNR measurement. The standard deviations will be obtained either directly from the covariance matrix of the Kalman filter or from calculations based on the radar parameters.

The maneuver data-to-track association window will be the Position Locus Curve, shown in Figure MDWP-1, coupled with the velocity, altitude and RCS measurement to the level of confidence that exists for a maneuvering target.

The data-to-track association window for the KBT is similar to that for a conventional tracker. (Note that the size of this window will vary as a function of the time since the last target measurement.) What is unique for the KBT is that non-traditional parameters will be included in establishing the window size. For example, the RCS can be an especially useful discriminant for tracking a LO target, whose fluctuations would be more Swerling Case 0 or 3-like than Case 0. If the target's RCS fluctuates significantly from scan to scan, the RCS will not be a useful discriminant for association. However, as σ_{RCS} for that target will be large, this parameter would be weighted very lightly in the data-to-track association process. The technique that will be used to pair threshold crossings with existing tracks (e.g. immediate assignment by minimum distance, minimum total mean-square error for all detections within the window) will depend on the association algorithm that is used.

Ideally, the target discriminants such as RSM signatures, length measurements, etc. would also be included in the data-to-track association process. As discussed in the introduction of this document, this will not be possible to model for the KBT simulation.

There is virtually no impact on the KB Controller for the Data-to-Track Association Window Dimension Rule.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Maximum-G turn capability of high-priority targets
2. Maximum acceleration/deceleration rate of high-priority targets

Data required from radar to implement rule:

1. SNR of detection

2. Target altitude

3. Measurement accuracies (ΔR, $\Delta\theta$, Δf_d)

4. Spectral features (if available)

Data supplied to KB Controller as result of rule:

None

Data supplied to radar as result of rule:

None

9.24 Disconnected Tracks Association Rule:

If 1) an existing track is lost, and 2) a new track is spawned, and 3) the time of the last detection on the lost track is within four (INITIAL ESIMATE FOR THIS PARAMETER) radar dwell times of the initial detection, and 4) the initial detection for the new track is within a *reasonable* distance of the last or second-to-last detection of the lost track, and no priority data exists for the new track, then the priority of the target for the lost track will be assigned to the new track.

The purpose of this rule is to quickly make a reasonable estimate of the priority of a target on a newly generated radar track. For example, a track can be lost due to the target's velocity vector becoming perpendicular to the radar's LOS vector, to terrain obscuration, to jamming or strong clutter, to discretes or ground traffic, etc. Also, a target could execute a very-high-G maneuver for a short period of time, and then return to a constant velocity trajectory. In such cases, a new track will soon be observed that has a very high correlation with the previous track, especially if there are not a lot of other targets in the vicinity.

To minimize the difficulty in establishing the priority of the new track when it is highly probably that the two tracks were for the same target, the priority of the old track will be assigned to the new track. This will allow the KBT to quickly assign the appropriate TSPL to the new track. This association would be strengthened if, for example, a condition existed such as an obstacle that could be the logical cause of a maneuver or obscuration.

NOTE: the Track Association Rule will require some additional processing by the KBT and the KB Controller. It will be necessary to project from the original track to the new track to determine whether the points at which the detections were made are compatible with the kinematics assumed for the target (e.g. could it make a turn having the required number of Gs or could it accelerate/decelerate at the required rate for the tracks to merge). This testing must be done under several possible hypotheses such as: 1) the last detection of the original track was valid, 2) the last detection of the original track was a false alarm, 3) the last two detections of the original track were false alarms, etc. Thus some computations will be necessary; however these should not have to be performed very often.

KBT / KB Controller / Radar Interface

Data required from KB Controller to implement rule:

1. Target priority (U) (optional)
2. Obstacle locations and dimensions in vicinity of high-priority targets (U?) (optional)
3. Detection reports from other sensors (U) (optional)
4. Maximum-G turn capability of high-priority targets (optional)
5. Maximum acceleration/deceleration rate of high-priority targets (optional)

Data required from radar to implement rule:

None

9.25 NEED RULES

How to identify discretes and roads

Roads: (x, y) of cells with movers, maximum radial velocity → aspect angle

Predicting when maneuvers will occur – minimum-G turn

Predicting obscurations if height is not known

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